Human Spaceflight Capabilities

Vertebral strength and fracture risk following long duration spaceflight

Completed Technology Project (2015 - 2017)

Project Introduction

Mechanical loading is required for maintenance of the musculoskeletal system. Thus, exposure to microgravity induces marked bone loss in both humans and animals, and is a major concern for astronauts exposed to long-duration spaceflight, as they may be at increased risk for skeletal fragility and bone fractures. Most prior studies have relied on dual-energy X-ray absorptiometry (DXA), a 2D technique used to assess bone mass at different skeletal sites, to assess effects of spaceflight on bone strength and fracture risk. However, DXA-based measurements are limited in several regards. First, whole bone strength is determined by bone mass, bone geometry and intrinsic properties of the bone matrix — and DXA is only able to assess bone mass. Second, DXA measurements are subject to technical artifacts due to overlying structures (e.g., aortic calcification), degenerative changes (e.g., osteophytes), and differences in body size between individuals and within an individual over time. Third, DXA measurements are inadequate for identifying mechanisms underlying skeletal fragility, as they cannot distinguish changes in trabecular versus cortical bone. Newer technologies, including 3D quantitative computed tomography (QCT) are able to overcome the limitations of DXA. Moreover, QCT images can be used to estimate bone strength using a standard engineering approach called finite element analysis. Indeed, QCT images have been used successfully to demonstrate negative effects of spaceflight on hip bone density and strength. However, a similar examination of the effects of spaceflight on vertebral strength has not been performed. Thus the degree of spinal deconditioning and subsequent risk of vertebral fracture following long-duration spaceflight remains unknown. Our central objective is to address this gap in knowledge by assessing changes in volumetric bone density and strength of lumbar vertebrae using previously collected QCT scans from long duration ISS crewmembers. In addition, since bone fractures occur when the forces applied to the bone exceed its strength, we will also estimate the risk of spine fracture by computing a load-to-strength ratio in each astronaut for different activities of daily living. Vertebral strength will be measured using an FDA-approved method that employs finite element analyses of QCT scans, and has been validated against in vitro bone strength testing as well as in large, population-based studies of spine fracture. We will estimate loads applied to the spine using a musculoskeletal model of the lumbar and thoracic spine that can be adjusted to reflect the astronaut's height, weight, spinal shape and specific trunk muscle anatomy — all factors that are important contributors to spinal loading. This work is highly significant to NASA as bone loss and increased fracture risk following long duration spaceflight remain key operational concerns. Specifically, the proposal directly addresses several risks outlines in the Human Research Program (HRP) Program Requirements Document from 2009: 1) Risk of injury from dynamic loads; 2) Risk of bone fracture; and 3) Risk of early onset osteoporosis due to spaceflight. Further, the proposed work addresses several gaps identified in the Integrated Research Plan, including: 1) OP5: We do not know the extent to which spaceflight deconditioning decreases injury tolerance for dynamic loads; 2)

Vertebral strength and fracture risk following long duration spaceflight

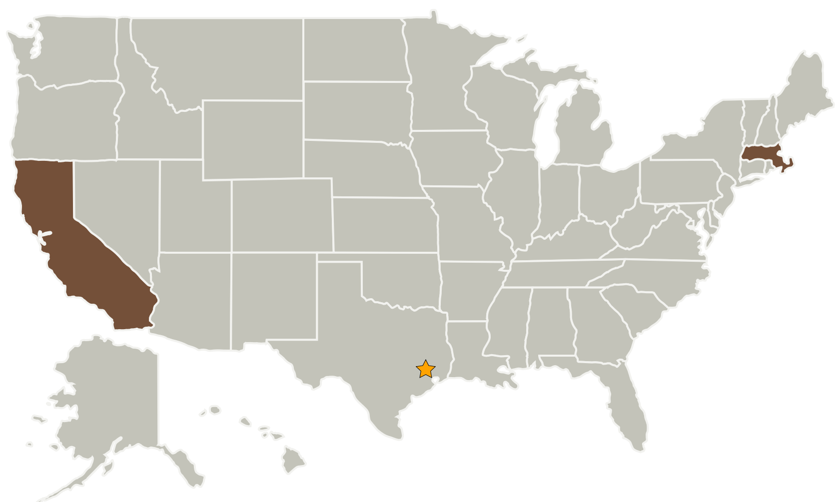
Table of Contents

Fracture 3: We need a validated method to estimate the risk of fracture by evaluating the ratio of applied loads to bone fracture loads; and 3) Osteo 3: We need a validated clinically relevant method for assessing the effect of spaceflight on osteoporosis or fracture risk in long-duration astronauts. Improved understanding of the effects of spaceflight on vertebral fragility and spinal loading will allow development of effective countermeasures to reduce the risk of bone fracture in astronauts, and may lead to improvements in assessment of spine fracture risk in older adults.

Anticipated Benefits

Improved understanding of the effects of spaceflight on vertebral fragility and spinal loading will allow development of effective countermeasures to reduce the risk of bone fracture in astronauts, and may lead to improvements in assessment of spine fracture risk in older adults.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Johnson Space Center(JSC)	Lead Organization	NASA Center	Houston, Texas
Beth Israel Deaconess Medical Center, Inc.	Supporting Organization	Industry	

Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Center / Facility:

Johnson Space Center (JSC)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

David K Baumann

Principal Investigator:

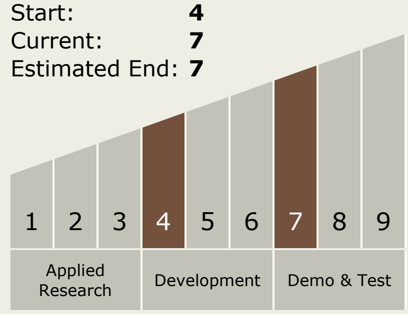
Mary L Bouxsein

Co-Investigators:

Tony Keaveny
Stephanie Wasserman
David Kopperdahl

Technology Maturity (TRL)

Start: **4**
Current: **7**
Estimated End: **7**



Primary U.S. Work Locations	
California	Massachusetts

Project Website:

https://taskbook.nasaprs.com

Technology Areas

Primary:

- TX06 Human Health, Life Support, and Habitation Systems
  - └ TX06.3 Human Health and Performance
    - └ TX06.3.6 Long Duration Health

Target Destinations

The Moon, Mars